SOVIET HIGH-POWER TRANSMITTERS: PARTIAL REPORT I

Source: Books and periodicals as indicated

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[Limitations of time and personnel made a thorough literature survey of this subject impossible, but in view of the need for this type of information, publication of a partial report was considered desirable. The report is divided into three sections. Section I gives information, probably very incomplete, on existing high-power transmitters in the USSR. Section II is concerned with the technical details of some Soviet high-power transmitters. Section III lists some articles for which further exploitation may be desirable.]

I. Existing High-Power Transmitters in the USSR

The following high-power broadcast transmitters were listed as existing in the USSR as of 1 July 1935 (Radioyezhegodnik -1936):

Station	Antenna Power (kw)	Frequency (kc)	Wavelength (m)
Moscow, RV1, imeni Komintern	500	172	1744
Novosibirsk, RV-76	100	217.5	1380
Leningrad, RV-53	100	245	1224
Moscow, RTsZ, RV-43	100	271	1107
Moscow, VTsSPS, RV-49	100	401	748.1

In addition, the 120-kw short-wave radio station RV-96, stated to be the most powerful in the world, was constructed in the period 1936-1938. ~~In addition,~~ reference has ~~frequently~~ also been made in Soviet literature to a very high-power station built during the war (Vestnik Svyaz' - Elektrosvyaz', No 5, 1948, p 11). A 1947 paper reported that the 4th largest radio station in the USSR was put into operation in 1946 (location not stated) and that powerful radio stations had been built in Riga, Simferopol', Stalingrad, and other cities (Vestnik Svyaz' - Elektrosvyaz', No 1, 1947, pp 4-5).

Although the 500-kw station is the most powerful mentioned here, the text of section II seems to indicate that a 900-kw station is in operation.

II. Technical Details of Some Soviet High-Power Transmitters

The major pobtion of this section was taken from the book Peredayushchiye Radiotsentry (Radio Transmitting Centers) written by L. A. Kopytin and published by Svyazizdat in 1951. Stations with a power of 100 kw and later 500 kw were constructed by a group of Soviet engineers under the direction of A. L. Mints. The latter is the outstanding Soviet scientist in the field of high-power radio station construction, and it is intdresting in this connection to note that he invented "a device for paralyzing the operations of an enemy radio station" while still a student in the Physico-Mathematical Faculty of Moscow University (Slovar' Radiolyubitel', Radio Amateurs Dictionary, S. E. Khaykin, 1957). It is claimed that frequency modulation was used for the first time in this invention. In 1924, Mints directed the construction and subsequently the operation of the Sokol'niki Radio Station of the Scientific-Research Institute of the Red Army. Since 1928, Mints has headed the Bureau of Powerful Radio Construction, which has built all the powerful radio stations in the USSR. He designed a new type of antenna which permits directional transmission over a wide frequency band for the 120-kw RV-96 short-wave station. Mints also directed the construction of the station built in the first years of World War II; the latter station is claimed to be the most powerful in the world.

With regard to the technical details of the powerful stations, Kopytin's book states the following: Experience has shown that it is not efficient to use powerful stations on medium waves in the 200-550 m band. Therefore, most powerful radio stations operate in the 1,000-2,000 m band or in the combined long and medium-wave band.

The power of radio stations is increased by connecting several tubes in parallel. This system has the following defects, which increase with decreasing wavelength: connection of many tubes in parallel causes a considerable increase in the size of the power stage and makes necessary long connecting wires, which leads to unstable operation of the stage and makes it susceptible to self-excitation, parasitic oscillations, and non-uniform loading of the tubes because of differences in their parameters. These defects were partially eliminated by introducing symmetrical circuits dividing the tubes into two branches.

Division of the power stage into a number of separate units was used to ~~xxxxx~~ increase the power of stations. In 1930, Z. I. Model', at the request of Al L. Mints, investigated in detail problems involved in the operation of radio stations whose output stage consisted of a large number of ~~xxxxx~~ units connected in parallel. This work not only established a theory for this type of circuit but also enabled Soviet designers to build continously-operating radio stations by connecting in and disconnecting units without interruption in service, by distributing the load between them, etc.

In the unit type of construction of radio stations, the total power is developed by several separate units working into a common circuit (Figure 1). Each of these units has several power tubes connected in a symmetrical circuit. The basic characteristic of the unit system is that in-phase operation of all the units must be maintained. In the general case, the amplitudes and phases of the voltages in the plate circuits of all units must be equal to each other to ensure uniform power delivery and ~~xx~~ good quality indices. The assembly, construction, and arrangement of parts in the units must be identical. The equivalent resistance introduced by the common circuit into the plate oscillatory circuit must be the same for each unit. If one of the units operating in parallel is suddenly disconnected, the operating conditions of all remaining units are changed. The greater the number of units, the less change there will be for the units remaining in operation.

In normal operation, the resistance introduced into the oscillatory circuit of each unit is $r_k = \frac{n \omega m^2}{R}$. If one of the units is disconnected, $r_i' = r_i \frac{n_1}{n}$, wherein n denotes the number of unit remaining in operation. The resistance introduced decreases and the equivalent resistance R_{oe} increases. This changes the operating conditions of the unit. If the tubes were underdriven, they become overdriven and the current in the plate circuit increases. If the tubes were overdriven, the current increase is negligible.

To restore the operating conditions, we must increase the coupling of all the remaining units with the common circuit. This measure would be sufficient if the dis-

~~xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.~~

connected unit were not electrically coupled to the common circuit. But actually the unit at the first instant is coupled with the common system through the coupling coil.

A voltage is built up in the plate circuit which may reach high values, especially in normal operation of the units under underdriven operating conditions. Dangerous overvoltages may arise in the unit. For example, if the filament of the disconnected unit is still energized, the tubes will operate as rf rectifiers and a dc voltage considerably above normal will appear on the filter of the rectifier in the given unit.

To eliminate undesirable effects and to maintain correct operating conditions of the units remaining in operation when one unit is disconnected, the tuned circuit of the disconnected unit must be quickly detuned. This is done by ground part of the turns on the inductance coil. In addition, coupling with the common circuit is eliminated, e.g., by removing the coupling coil.

At the station imeni Komintern, the coupling is decreased rapidly by the use of two coils made in the form of flat spirals. When the unit is disconnected, one of these coils (the unit coil) drops down, becomes grounded, and detunes the plate circuit in which it is connected. Coupling may also be eliminated through the use of high-frequency fast-acting contactors which interrupt the plate circuit. Systems similar to fast-acting dc automatic intdrruptors may be used for this purpose or they may be made in the form of a disconnect switch having a rubbing contact instead of a slot at the end. The contact consists of a wide copper disc which conducts heat well. The knife of the disconnect switch is coupled through an insulating rod to a dc solenoid. When the solenoid is energized, the core is pulled in and the rod is pulled down, producing a short circuit by pulling the copper disc onto the fixed contact. The contactor is equipped with an air damper and can pass rf currents of 150 a at 12,000 v.

In order to improve the operation of contactors interrupting the rf circuit, systems are used which before disconnection remove momentarily the rf excitation or reduce the plate voltage by acting on the grids of the thyratrons or on the mercury rectifier.

In radio stations built onx the unit principle, the coupling coils of the common circuit may be connected either in series or parallel with the plate circuits of the units (Figure 2). The operating conditions of a multi-unit transmitter are more stable with the parallel circuit, as was shown by Z. I. Model'. The current in the tuned circuit of the disconnected unit is less than if the coils were connected in series. This advantage is not so marked for the shorter wavelengths (200-300 m). Series connection of the coils is complicated by the fact that the coils are at different potentials with respect to ground and the parasitic capacitance to ground causes different operation of the individual units. In addition, wiring inductance must be taken into consideration.

It is also necessary that supply of the grid circuits of the individual units be in phase and identical. This is done either by maintaining strict symmetry in assembly using feeders of equal length as is done is feeding cophased antenna arrays or by artificially equalizing the grid feeders by connecting in inductances.

The 500-kw Station imeni Komintern

The radio station imeni Komintern is an example of the multi-unit system of constructing the output stage. There are seven units, six operational and one spare, in the power stage of this station.

Each unit has its independent power supply. The coils coupling the common circuit with the units are connected in parallel.

There are a total of seven stages in the transmitter. The grids of the stage IV tubes are used for rf modulation. The last three stages, V, VI, and VII, amplify the modulated oscillations. Complete spare units are available for the first six stages. The antenna is suspended from four 200-m metal towers and has three T-sections placed in a straight line.

The unit system for constructing a transmitter output stage can also be used in the low-frequency section. In transmitter systems where the modulator power is comparatively low, the unit system is used only in the output stage of the rf section, but in transmitter systems having class B modulation, the modulation is performed in the last stage and therefore the power of the modulation unit increases considerably. In the latter case, use is made of a system proposed by A. L. Mints in 1934 in which each rf unit has its own modulation unit, which simplifies the transmitter circuit and makes the individual units more flexible.

In order to ensure identical modulation of the individual units, the rf units must be tuned accurately to the carrier frequency. The phase and amplitude of the individual modulating voltages must also be alike throughout the audio range.

The radio station imeni Komintern has one common power stage VI which feeds the grid circuits of the six parallel units in stage VII.

Another radio station, built later, has three two-stage units, i.e., the units are built according to the two-stage unit system (Figure 3). Here, the common exciter feeds the pre-power and power stages, which requires that identity with respect to phase and amplitude must be maintained in stage VI as well as in stage VII. Many short-wave transmitters use this system.

A Long-Wave Radio Broadcast Station With the Unit System in the AF and RF Sections

A block diagram of a unit-system radio broadcast station with plate modulation is shown in Figure 3. The rf section of the transmitter consists of seven stages. The first three stages are combined under the general title of "exciter". This is followed by two amplifying stages, after which the rf energy is fed to a transfer switch which directs it into three separate units. In distinction to the station imeni Komintern, each unit consists of two stages (VI and VII). The power from the three units is fed into a common circuit, the coil of which is connected in series. To reduce the voltages with respect to ground, the total capacitance of the circuit is distributed into groups connected around each unit. The af section consists of two preamplifiers followed by three units, each of which consists of two amplifying stages.

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In the class B modulation system, each oscillator unit ~~has~~ is followed by its own modulator. Each unit develops power of 165 kw with a total antenna power of 500 kw. Double units, one operational and one spare, are installed for all stagesup to the fifth, inclusively.

The filaments of the tubes in stage VII, which ~~xxx~~ are indirectly heated, are supplied with ac. The filaments of all remaining tubes are supplied with dc, obtained from selenium rectifiers. Three metallic mercury-arc rectifiers are used to supply the plate voltage of 12,000 v. The system permits operation with an arbitrary number of units, but the transmitter must be disconnected for a short period to effect any change.

In order to maintain stable operating conditions in stage V, its load must remain constant regardless of the number of units operating. This is accomplished by connecting in additional resistances instead of inoperative units through a transfer switch.

A phasing oscillator is provided in the circuit to compare the phases of the separate ~~xxxxxx~~ units. The voltage from the plate circuits of all the sixth and seventh stages are fed to the oscillator through six high-frequency cables. The measuring instrument at the phasing oscillator permits one to measure and equalize the voltages in the circuits of stages VI and VII. After this, the units may be put into joint operation.

The commercial efficiency of the station is 36%. Harmonic distortion is 2.2-3.7% for a modulation index of 80%. The voltages in the plate circuits of the units must be checked daily. The phases are checked only when the station changes from one wavelength to anbther or after the operating conditions are changed.

Stations built more recently (1940) has a very low-power common exciter, and each unit is a multi-stage transmitter. This permits the use of standard broadcast transmitters in the~~xx~~ construction of powerful stations. The number of transmitters used depends upon the output power required. This construction is also advantageous ~~fxxx~~ in that it provides spares for the transmitter, since instead of the separate stages, rectifiers, circuit elements, etc. usually used for spares, an entire transmitter may be considered a spare in this system. If one of the transmitters breaks down, the rest of the transmitters remain in operation with a corresponding decrease of total power. Modern methods of designing unit systems and the switching equipment presently available has so simplified the overall circuit that there is a tendency to produce even the less powerful transmitters in the form of two independent transmitters operating together (e.g., 100 + 100 kw).

The principle of parallel connection of two transmitters was proposed by I. Kh. Nevyazhskiy in 1935 and was used in the construction of one of the shortwave stations. In this station, separate operation of two transmitters was used, with a common exciter and two antennas having the same radiation pattern.

One great merit of the principle of addition in space is the fact that the transmitters are not coupled together by a common tuned circuit or antenna. This eliminates the need for additional regulation of the transmitter when the second one is connected in.

A defect of this method is the sharp drop in audibility for the listener when a unit is disconnected. The drop in audibility is proportional to the square of the number of units connected because of the decrease of total power. The total power decrease because of both disconnection of the unit and poorer antenna directivity. In addition, this system requires careful checking of the polar diagram of the antenna, since if the two separate diagrams are not symmetrical, distortion will result. This defect gave rise to the system of adding powers in the feeder.

In adding up the powers of separate transmitters or separate units, the individual sections must be phased. This is usually done by connecting a phase-shifting device in one rf section. When the power of separate transmitters is to be added, the phase of each transmitter is compared with the phase of oscillations created by a standard oscillator.

The electrical circuit for connecting in a phasing unit is shown in Figure 4. Transformers of the type T_1, T_2, T_a, and T_e are used to apply controlled voltages to the oscilloscope.

The amplitude and phase are compared by successively connecting each transmitter into a dummy antenna and comparing it with the phase of the master oscillator using an oscilloscope. The voltages are fed to the two pairs of plates and the picture is observed. The phase and amplitude are equalized by using the phasing unit of the transmitter which permits the phase to be shifted by 360°. Each transmitter is adjusted to obtain an equal value of rf at equal plate voltages and at equal dummy-antenna power.

The phasing unit shown in Figure 5 is a two-stage rf amplifier. This unit serves only to control the voltage by changing the capacitance C_2 and to adjust th phase, roughly by capacitance C_8 and more accurately by aapacitance C_4. The switch S_2 serves to shift the phase b y 180°.

A Powerful Transmitter With Division of the RF Section into Separate Channels

In order to reduce the number of tubes connected in parallel, one of the long-wave broadcast transmitters uses a system in which the rf channels are separated (Figure 6).

The total power of the radio station is obtained by adding the power of two separate transmitters, having a common exciter. Each transmitter works into its own antenna. Both antennas are suspended from the same supports. T

The half-power of the transmitter (450 kw) is developed by 8 tubes. Only two tubes are connected in parallel. This is possible because of the use of phase-amplitude modulation. Phase-amplitude modulation is based upon the division of the transmitter into two rf channels. The tubes of the last stage in each of the channels are in telegraph operation with high (utilization?) of the plate voltage. The rf power of each channel is combined in the common oscillatory circuit. The phase of the rf oscillations in each channel is different. In modulation, the current in the antenna is changed by a symmetrical variation of the phase of the oscillations in each of the channels. Thus, modulation consists essentially of the addition of two vectors, one displaced relative to the other by a certain phase angle. The less the angle, the larger their sum and the greater the antenna current.

On the negative alternation, the tubes of one of the channels are not modulated and do not radiate power. The antenna current is created, as is customary, in the stages amplifying the modulated oscillations and consequently, the phase of the current is not changed, but only the amplitude of oscillations. When the positive alternation is reached, the amplitude remains unchanged, the phase changes and the energy is combined with the energy of the second channel. This variation of the system is used to improve the over-all efficiency of the transmitter.

The phase and amplitude are controlled in modulation in one of the low-power stages, after which the section is split into two channels.

The power stage of each of the channels is designed symmetrically, so that two tubes operate in each branch. Allowing for circuit losses, each of the tubes develops an oscillatory power of 60 kw at the carrier frequency. Each of the channels puts out one-fourth of the total power. The half-power appears in the common circuit and the full power is obtained by adding the two half-powers in space. The use of this principle permits us to reduce the number of tubes connected in parallel.

The transmitter is arranged on three floors, occupying 1,000 m^2 on each floor. The power stages are in the open and the low-power stages are enclosed in cabinets. The transmitter is controlled from a board. Each half of the transmitter may use either both antenna systems in half-power operation or one of them in joint operation. The oscillatory circuits contain capacitors whose plates are placed in hermetically-sealed tanks under up to 15 atm pressure.

Beneath the transmitter room of the building are the power supply filters and ceramic water tanks. All the distribution busbars and power-frequency and rf cables pass through this room. The boards for water control and boards for switching in various circuits are also located on this floor.

The mercury-arc rectifiers and machines for supplying filament power, which producing a current of 6,200 ampheres each at 35 v, are on the first floor. The filament conductors are aluminum busbars. The pumps for the cooling system, heat exchangers, etc are located in the basement.

The antenna system is supported from four towers each 250 m high, placed in the corners of a square 400 m on a side. The antenna system has five legs. Of these, four are formed by the towers and the supplementary wires while the fifth is suspended by ropes in the middle of the square. The complex antenna system employed permits us to obtain field intensity equal to 30.4 mv/m per kw radiated power at a distance of 10 km, which is very good for an operating wavelength of 1600 meters.

The efficiency of the power stages with respect to plate supply is 62% for a modulation index of 0 and 58.5% for an index of 80%. The frequency response is linear from 50 to 5000 cps, having a deviation of ± 1 db in this range and ± 2 db from 50 to 8000 cps. The noise level for a modulation index of 80% is equal to 60 db.

Addition of the Power of Transmitters Operating in Parallel.

As an example of addition of the power of transmitters, we select radio broadcast stations consisting of two 200 kw transmitters operating in parallel or four such transmitters operating in parallel, giving a total power of 800 kw. Each transmitter has its own modulation unit (plate modulation) and separate power packs. The power is added in the feeder without the use of a common circuit (Figure 7). The 400-kw transmitter may operate on long- and medium waves into a special antenna network suspended from two metal towers each 200 m high. The antenna is of unique design. On long waves, it functions as two L-networks extended in a straight line but facing opposite sides. On medium waves, these two networks form a horizontal dipole. A similar sedond dipole is suspended parallel to the first but closer to the ground.

In the circuits protecting the units from overvoltages when one of them is disconnected, a system of cutting off excitation is used. This system is shown in Figure 8 for two transmitters operating in parallel. The carrier is removed by the first tube if there is no plate voltage on the unit. This is done by virtue of the fact that the plates of the tube in the protective circuit obtains its voltage through a divider from the same high-voltage rectifier used to supply the first transmitter. A second tube, connected in the plate voltage circuit of the second transmitter, functions in the same fashion. A third tube cuts off the excitation of the power stages if a protective relay in the common circuit is actuated, e.g., during a short circuit in the feeder. When the transmitter is tested on a dummy antenna, the circuit is automatically supplied from its own 300-v rectifier. When the transmitter is changed to operation into the antenna, switching of the power supplies is done automatically.

When a unit is switched out during operation, the excitation is not connected in until the unit which was disconnected is connected back in or until its coupling coil is disconnected from the common circuit. The protective circuit is connected in after the common master oscillator but before the circuit is branched off into separate channels.

An additional protective circuit is employed to prevent overvoltages in the modulation unit circuit when the carrier is removed. The protective relay is supplied through a rectifier from the grid current of the rf power stage. If there is grid current in the rf power stage, the relay contacts are open. If excitation is removed, the grid current drops off and the relay contacts close to short-circuit the audio-frequency circuit in one of the low-power stages.

The use of these protective circuits requires complete transmitter stability with the excitation removed and with the full plate voltage applied, since the excitation is applied only after the high-voltage is applied to the plates of the tubes.

The plate voltage on the separate transmitters is removed and applied by means of a push button. If one of the transmitters is disconnected because of a short circuit in a tube, the repeated reclosing relay operates. At this time, the excitation is removed and both transmitters are inoperative. If after the second closing of the relay, operating conditions have been restored, the transmitters are automatically put into operation; if not, the high voltage of the faulty transmitter must be removed and the push button control is rendered inoperative. The tuned circuit of the faulty transmitter is disconnected and coupling for the smaller number of simultaneously-operating transmitters is selected. After this, the system is put back in operation. All these operations require only a few seconds.

In addition, a device is providdd to protect the transmitter from overvoltages. The device is based on the fact that under normal operating conditions, the impedance of the tuned circuit Z_c remains constant. If a fault appears in the antenna or in the rf cable, the value of Z_c changes, which in turn changes the ratio of voltage to circuit in the tuned circuit. The circuit of the device is shown in Figure ~~10.~~ 9

The current transformer supplies to the dry rectifier an rf voltage proportional to the current in the tuned circuit. The choke coil connected in parallel with the tuned circuit makes it possible to take off a voltage proportional to the voltage on the tuned circuit. This voltage is fed to a separate dry rectifier. Through variable resistors, the rectified currents are applied to the windings of a differential relay.

The circuit is adjusted so that the relay is in the neutral position and its circuit is open when the transmitter is operating correctly. If a fault appears in the rf section or if the normal tuning circuit is disturbed, the ratio of current and voltage changes and the relay, in closing, sends a current pulse to a unit which removes the excitation from the power stages. Removal of excitation also removes the relay supply and the transmitter is switched on again. If the fault has been eliminated, operation may continue normally; if not, the circuit keeps operating in this fashion until the technician on duty disconnects the transmitter. The relay will not operate when the line voltage rises, since Z_c is not changed in this case.

A second protective unit, which cuts off the transmitter when the phase changes as well as when Z_c changes, is shown in Figure 11. Under normal operating conditions, Z_c is a pure active resistance. If detuning or a fault arises in the feeder, a reactive component is created which changes the ratio of currents and voltages. Two equal voltages are applied to the dry rectifier: one with the help of the current transformer, proportional to the current component, and one proportional to the voltages component taken from a capacitive divider. Both components are made equal and connected so as to oppose each other. If an inductive component appears, the phase is distrubed, the circuit becomes unbalanced, a voltage is applied to the relay, and the relay in operating closes a signal circuit. With the addition of an instrument in the relay circuit, this system may be used as a tuning indicator.

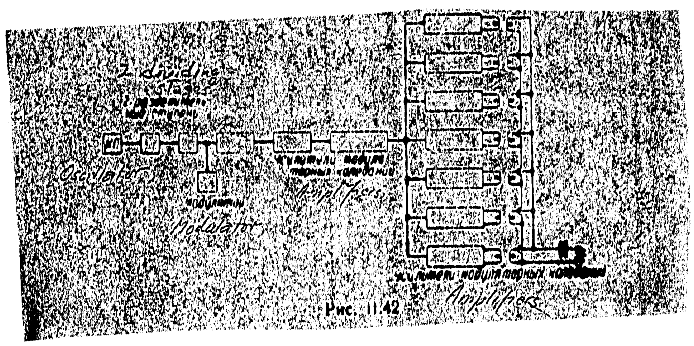

Рис. 11.42

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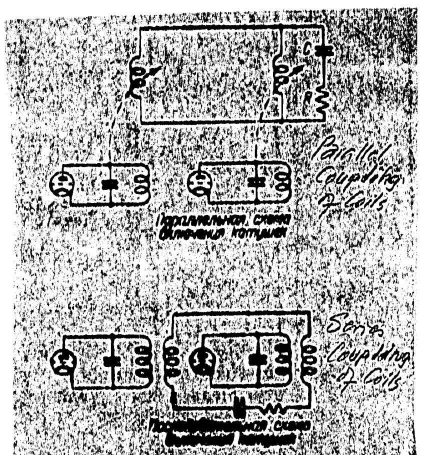

C
R
Parallel Coupling of Coils
Параллельная схема включения котушек
Series Coupling of Coils

Рис. 11.43

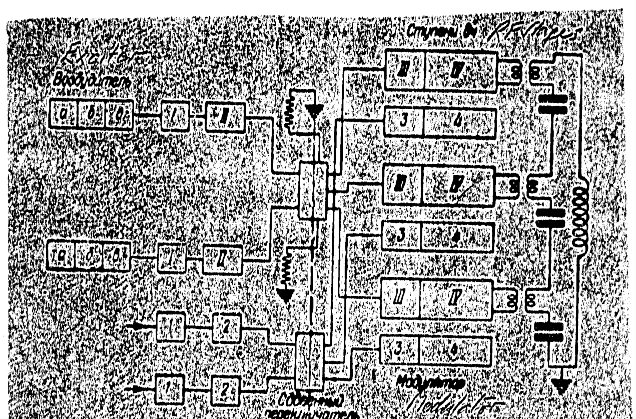

Exciter
Возбудитель
Ступени ВЧ
RF Stages
Модулятор
Modulator
Сдвоенный переключатель

Рис. 11.44

1 - Control Points (Common Output, Output 1 & 2)
2 - Crystal Oscillator
3 - Protective Unit
4 - Phasing Unit
5 - Transmitters 1 & 2
6 - Antenna
7 - Dummy Antenna
8 - Dummy Antenna
9 - Common Circuit
10 - Common Circuit of Dummy Antenna
11 - Fader
12 - Antenna Circuit
13 - Dummy Antenna
14 - Oscillograph

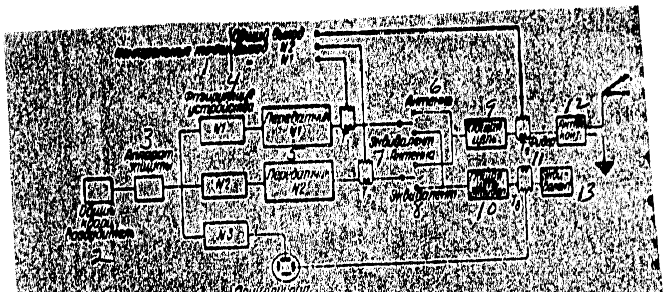
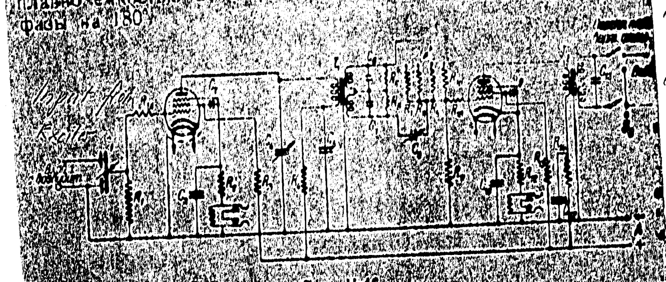


Рис. 11.45

Схема фазирующего устройства, приведённая на рис. 11.46, представляет собой двухступенный высокочастотный усилитель. Это устройство служит только для регулировки напряжения при изменении ёмкости C_2 и регулировок фазы грубо ёмкостью C_8 и плавно ёмкостью C_1. Переключатель S_8 служит для изменения фазы на 180°.

Phase-Shifting Unit



Output

Рис. 11.46

CONFIDENTIAL

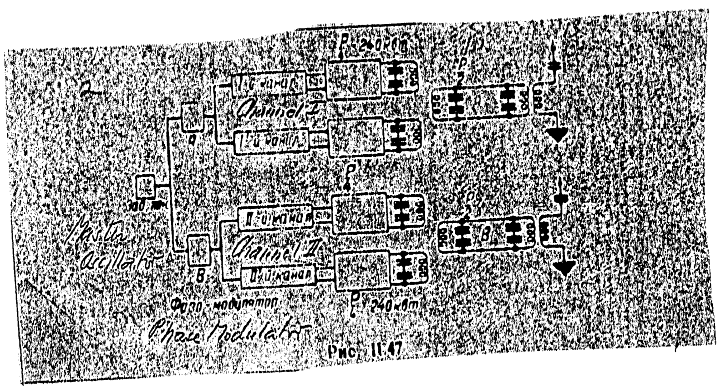


Fig. 6

CONFIDENTIAL

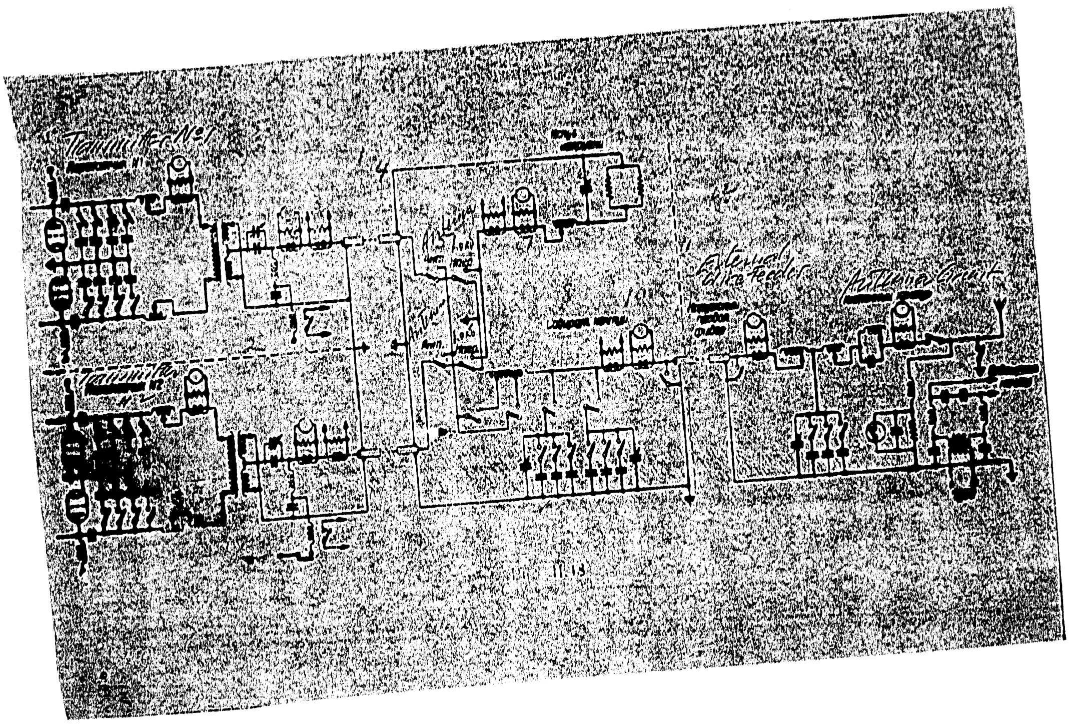


Fig 7

CONFIDENTIAL

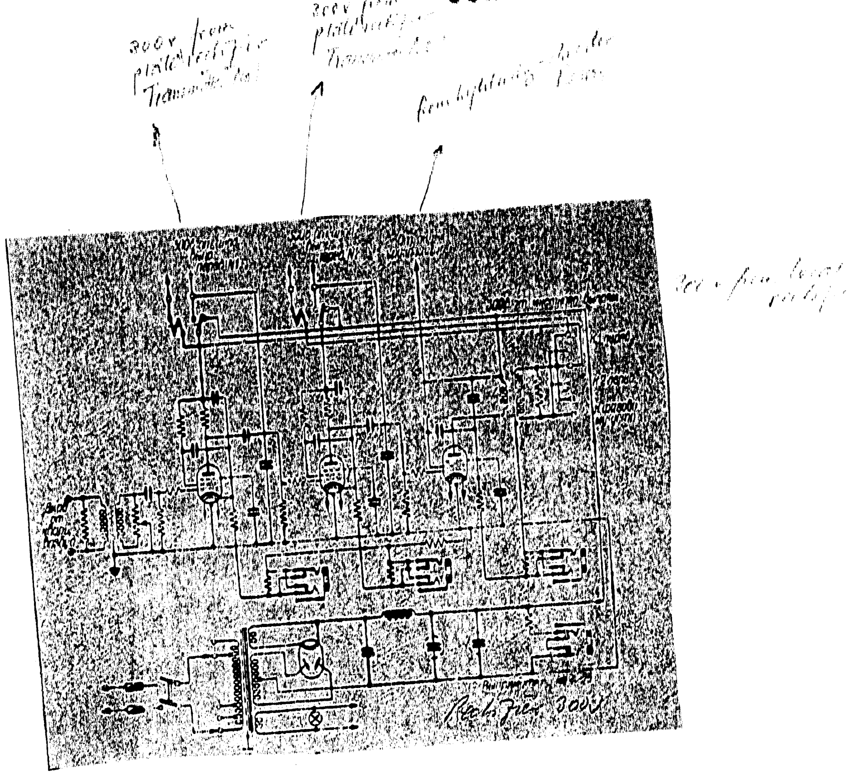


Fig 8

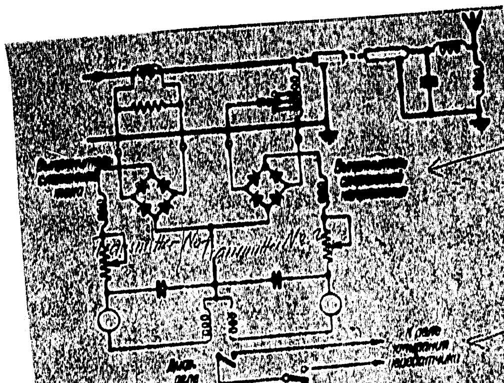
CONFIDENTIAL

CONFIDENTIAL

Current-Component Rectifier

Voltage-Component Rectifier

Fig. 9



To Transmitter Control Relay

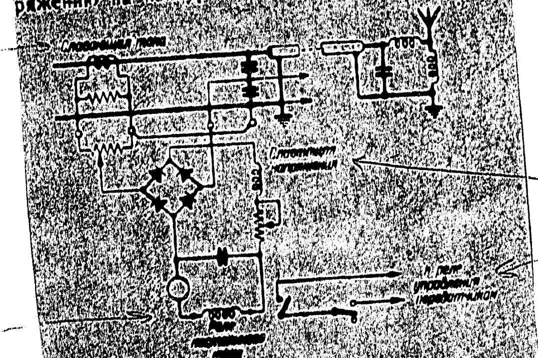
Differential Relay

Рис. 11.80

...ру дроссель позволяет снять напряжение, пропорцио...
...ряжению на контуре, которое и подается на отде...

Component Current

Fig. 10



Component of Voltage

To Transmitter Control Relay

dc relay

Рис. 11.81

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